Integration of 3D Seismic with Satellite Imagery at In Salah CO_2 Sequestration Project, Algeria

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Summary

The Krechba field is located in the Algerian central Sahara desert, and was developed in July 2004 as part of a joint venture with BP, Sonatrach and Statoil. The natural gas in the fields contains up to 10% CO_2, which has to be reduced to 0.3% before sale, resulting in the production of around 1 million tonnes/year CO_2. The CO_2 is re-injected into the water leg of the Krechba Carboniferous Sandstone gas producing reservoir (20 m thick) at a depth of 1,900 metres.

An exploration 3D seismic survey was acquired in 1997 but this was designed to image prospects in the Carboniferous and Devonian sequences rather than the overburden where quality is low. However, for sequestration monitoring the structure and characteristics of the overlying section are important for understanding and modelling of long-term behaviour. Further seismic survey(s) are planned for overburden imaging and 4D time lapse evaluation of CO_2 movement and long term sequestration in the subsurface. Time lapse satellite images (InSAR) collected since start of injection show clear ground elevation of up to 8mm/year around the three injectors while subsidence is apparent in the area of maximum gas production. The images have also confirmed the CO_2 is moving in the direction of preferred fracture orientation at reservoir level.

Integration of the 3D seismic with the satellite images, when combined with other measurements such as wellhead samples, is proving to be a powerful tool in tracking the subsurface migration of CO_2 at Krechba.

Introduction

Subsurface sequestration of CO_2 is becoming increasingly important as part of the ongoing climate change mitigation strategies being deployed around the world. Current efforts by the industry are focused on the development of a suite of CO_2 sequestration monitoring technologies which can be used to assist in providing a regulatory framework to allow subsurface CO_2 sequestration operators to undertake projects on a commercial basis.

The technologies being deployed and tested at various locations around the world include the whole gamut of traditional E&P techniques, including 3D seismic, observation wells, wellhead monitoring, surface flux measurements and gravity being a few examples. The primary objective in evaluating CO_2 sequestration sites is ensuring that long term (>1000 years) subsurface storage of injected CO_2 can be verified through short term monitoring and validation of predictive models up to the point when injection ceases (15-25 years).

There are currently three industrial scale CO2 sequestration projects ongoing in the world, namely Weyburn in Canada, Sleipner in Norway and Krechba at In Salah, in Central Algeria. The success of 4D seismic at Sleipner is well documented but not all fields/CO_2 storage sites are suitable for such techniques due to subsurface considerations. This may be the case at Krechba where detailed seismic modeling has suggested a limited 4D response at the injection level, especially at lower porosity intervals in the reservoir. Furthermore, changes in coupling, statics and local noise mean that land survey repeatability is unlikely to be as good as that currently achieved in marine 4D.

An approach taken at Krechba has been the integration of the current 3D seismic dataset with time lapse satellite images, injection history, wellhead sampling (pressures and fluid samples) and tracers. This has allowed the Krechba project team to understand the possible subsurface movement of CO_2 better in the absence of repeat seismic surveys.

A review of the satellite imagery data and its implications for the understanding of the subsurface movement of CO_2 at Krechba will be published in two papers by Don Vasco of LBNL (Geophysics in press).

Field Description

The Krechba field is located in the central Sahara desert in Algeria and CO_2 is re-injected into the water leg of the Krechba Carboniferous Sandstone gas producing reservoir (20 m thick) via three horizontal wells at a depth of 1,900 metres. CO_2 injection started in August 2004 and to date some 2.7 million tonnes of CO_2 has been injected.

The storage reservoir comprises an estuarine, deltaic sequence of channel sands with porosities ranging from 11-20% and permeabilities averaging around 10md. The injection reservoir is capped by around 950m of Carboniferous mudstones (Figure 1) that are unconformably overlain by approximately 900 metres of a mixed Cretaceous sequence of sandstone and minor mudstones – this latter sequence comprises the regional potable aquifer. Surface outcrop consists mostly of Cretaceous carbonates. The strata in the section appear to be flat lying with little visible structural disturbance though some surface lineaments are apparent from aerial photographs, possibly suggesting deeper rooted structural faulting or fracturing.

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Available information from cores, FMI and seismic data indicates the injection reservoir and the immediate overburden section is fractured, with the predominant fracture orientation being NW-SE. Recent tracer, wellhead and satellite image data would strongly support this conclusion.

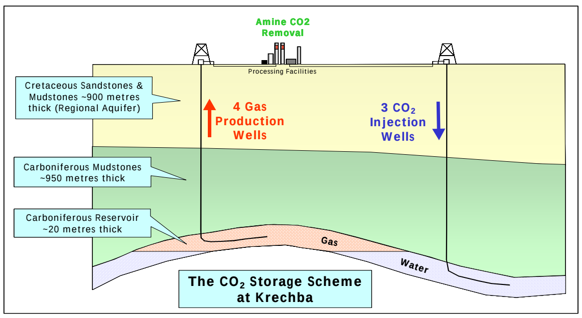

Figure 1: Schematic of Krechba Subsurface archtecture

Monitoring Technologies

A range of monitoring technologies have been, and will continue to be deployed, at Krechba but it was considered that key to these would be a repeat 3D seismic programme. The pre injection 3D survey was acquired in 1997 and the acquisition parameters were focused principally on the deeper reservoir sections, such that the imaging of the overburden sections is less than optimal for long term monitoring use (Figure 2). The 1997 3D has proved valuable for mapping lateral variations in reservoir quality; reprocessing in 2006 reduced noise and sharpened the image of the immediate overburden but could not compensate for artefacts introduced by the acquisition geometry which affect the shallower overburden including the Hercynian unconformity. There is no evidence of major faulting within the thick shale section but reliable interpretation of smaller scale structure is not possible due to the limited data quality and coverage.

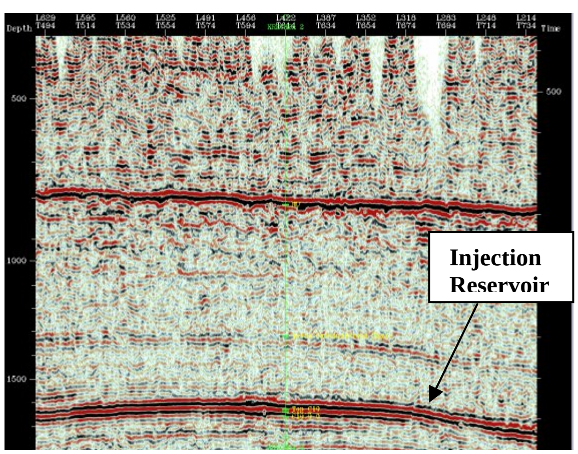

Figure 2: Krechba 3D seismic

Satellite Image data (InSAR) acquired since injection started in August 2004 has shown surface deformation around the injectors of up to 8 mm/year (in blue on figure 3), while the production area has shown subsidence of around 2-3 mm/year (yellowish areas on figure 3). Given the depth of injection and the geomechanical properties of the overburden, this was an unexpected result but one which may prove to be very useful for long term monitoring of the subsurface movement of CO_2 at Krechba (Figure 3).

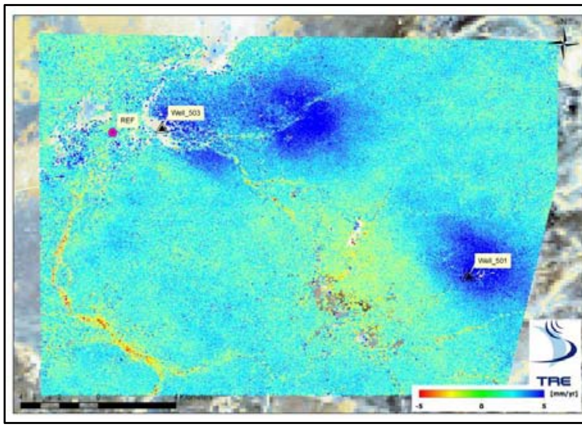

Figure 3: Ground Deformation at Krechba – 3 years of injection

Integration of the 3D seismic cubes with the satellite image data has revealed some interesting trends and insights into the structures at Krechba which may be controlling the movement of CO_2 in the subsurface. Initial observations indicate that deep seated (below reservoir) faults may control the Krechba structure at the Carboniferous injection level, resulting in fracture swarms running NW-SE along the east (and possible the west) flanks of the field.

Detailed analyses of the satellite images, and their correlation with the seismic cubes, confirms this interpretation of the probable CO_2 movement controlling mechanism at Krechba. Other information such as tracers and well head fluid samples and pressure data also confirm this interpretation.

These data are now being incorporated into detailed overburden models, incorporating discrete fracture networks, for long term plume evolution modeling.

Conclusions

Integration of 3D seismic with satellite images and other CO_2 monitoring and storage verification technologies at Krechba has proven to be very useful in developing an understanding, and models, of controls on CO_2 migration in the subsurface. It challenges common assumptions about the dominant flow direction and the importance of the pressure sink created by production.

Consideration is currently being given to the use of forward and inverse modeling of surface deformation, overburden geomechanics and injection volumes/pressures to assess the feasibility of using satellite imagery as a monitoring tool complementing the existing 3D seismic at Krechba.

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